 HB-11-585

OXC-4280

14 December 1962

Dear Gene,

As a result of our recent meeting, I thought it would be helpful to recapitulate the performance, and our plans to improve it.

The various enclosures provide the basis for the performance estimates shown in Table 1, which also shows some measured values:

System & Condition	Resolution Type	Predictions $\phi = 1.0$		Measurements $\phi = ?$	
		SW	AF	SW	AF
1A in C-123 LTF-16	Long	195-275	145-280	100-150	120-150
	Short	95-170	85-180	100-150	100-120
1A in JEWEL ATF-4	Long	75-80	35-55	~ 55	< 110
	Short	60-90	60-100	~ 50	< 110
1A in JEWEL at altitude	Long	145-175	120-180		
	Short	110-135	95-150		
1C in JEWEL at altitude	Long	~ 215	150-190		
	Short	~ 190	140-175		

TABLE 1: Performance Summary

These are the same values we discussed Tuesday, and, as I tried to point out then, our plan is to continue to use target images and test instrumentation results to diagnose the 1A system's behavior. The sine-wave targets are now completed, and this should speed progress as will the debugging of our instrumentation wiring, which is scheduled for January.

The upgrading of 1A is going ahead on the basis that some things are under our control and some are not, as summarized in Table 2.

Factor Affecting Performance	Degree of control we have over the factor	Plan of action
Seeing	Beyond our control	Attempt to confirm estimates from knowledge of all other transfer functions. Should be less harmful at altitude.
Atmospheric scattering, ∅	Beyond our control	Use sine-wave and gray-scale targets to correct photographic data. After enough data collected, predict usual range of ∅.
Optics	Test & Improve as needed.	Focus, and quality of flat mirrors is being tested & improved now. Aft alignment will be tested in January (at time analgesic is installed) and improved as needed.
Motion	Test & Improve as needed.	V/h-IMC and azimuth alignment are being tested now to permit optimum settings. Aft effective focal length will be rechecked and scanner balance will be improved in January. Improved support bearing scheduled for installation in January should improve stabilization to inherent limit of 1A. Other causes of image motion will be removed or lessened as identified in test program.
Film	Requires HQ participation with us and processor.	X-80 is superior to present processing, and we hope that the relative economy of improving images by use of this or a comparable formula will be carefully considered by all concerned.

TABLE 2: Plans For 1A Test & Improvement

To implement this plan, we will partially disassemble the 1A system in January and then resume flight testing and concurrent optimization in February. I know of no reason why the 1A system would not be available for operations in April, although its performance will be below 200 cyc/mm. (It may also be worthwhile to sandwich some further tests between operations.)

If desired, I will periodically bring these summaries up to date.

Best regards

Milt

Milt

mb

Enclosures

P.S. Also enclosed is the preliminary report for ATF-5.

MDR

Encl #1

OXC-4280

COPY 1 OF 1

Attachment 1 - Explanation of Graphs, which are basis of Table I

Graph 1

Red curves - Optics - The two curves represent the range of measured values on the forward optical bench using each of the four scanner flats oriented in position for nadir photography.

Green curve - Seeing - This curve is based on the same equation we have always used and first substantiated in our original proposal. Attachment 2 is the pertinent section of the proposal and the equation; we have no more recent information to suggest that the estimate is invalid. However, it should be obvious that the atmosphere could be extremely turbulent on some photographic days and thus lead to far poorer results than predicted. Since seeing should affect both resolution directions (long and short) equally, we might expect to discover when poor seeing limited performance by having equal resolution results in both directions.

Blue curves - Motion - The two curves in the long direction assume stabilization to be 3X out of spec and V/h to be (a) in spec or (b) 10% out of spec; since a periscope was used to measure V/h, this is reasonable. In the short direction, film sync is assumed to be 1σ lower, where σ is an estimate of sync error from tests run in December 1961, before the scanner bearings were modified. Heading error, which looks like a sync error, is assumed to be in spec, but this is too optimistic.

Solid Pencil curves - Modulation Transfer Function (MTF) without Film - Product of the 3 above curves. Intersection of these curves with the Modulation Detectability Curve (attachment 3) gives predicted AF target response, which is shown along the bottom scale of spatial frequency. Note that attachment 3 is for X-80 and this was not the actual development. At this time, we do not know how the modulation detectability curve looks for other developers.

Dashed Pencil curves - MTF with Film - These curves are the product of MTF without film and the MTF (not shown) of SO-132 developed in D-19. The point at which this curve has a value of 0.04 is the value we have used previously to predict performance for fully modulated ($M_o = 1.0$) sinusoidal targets with $\phi = 1$, where ϕ is the modulation reduction due to scattering (which causes brightness alterations).

Graph 2

Red curves - Same as graph 1.

Green curves - Same basis as graph 1, but more limiting due to higher Mach No.

Blue curve - Locked shuttle causes this much image motion in long direction. Short direction image motion cause is same as Graph 1, but longer exposure time (of ATF-4) results in more image motion (than LTF-16), and, therefore, a lower curve.

Graph 3

Red curves - Same as graph 1. Better scanner and folding flats could improve these.

Green curve - Same basis as graph 1, curve is the same as in proposal for good atmospheric conditions.

Blue curve - Assumes all motions in spec except stabilization and film sync out by 3X.

Graph 4

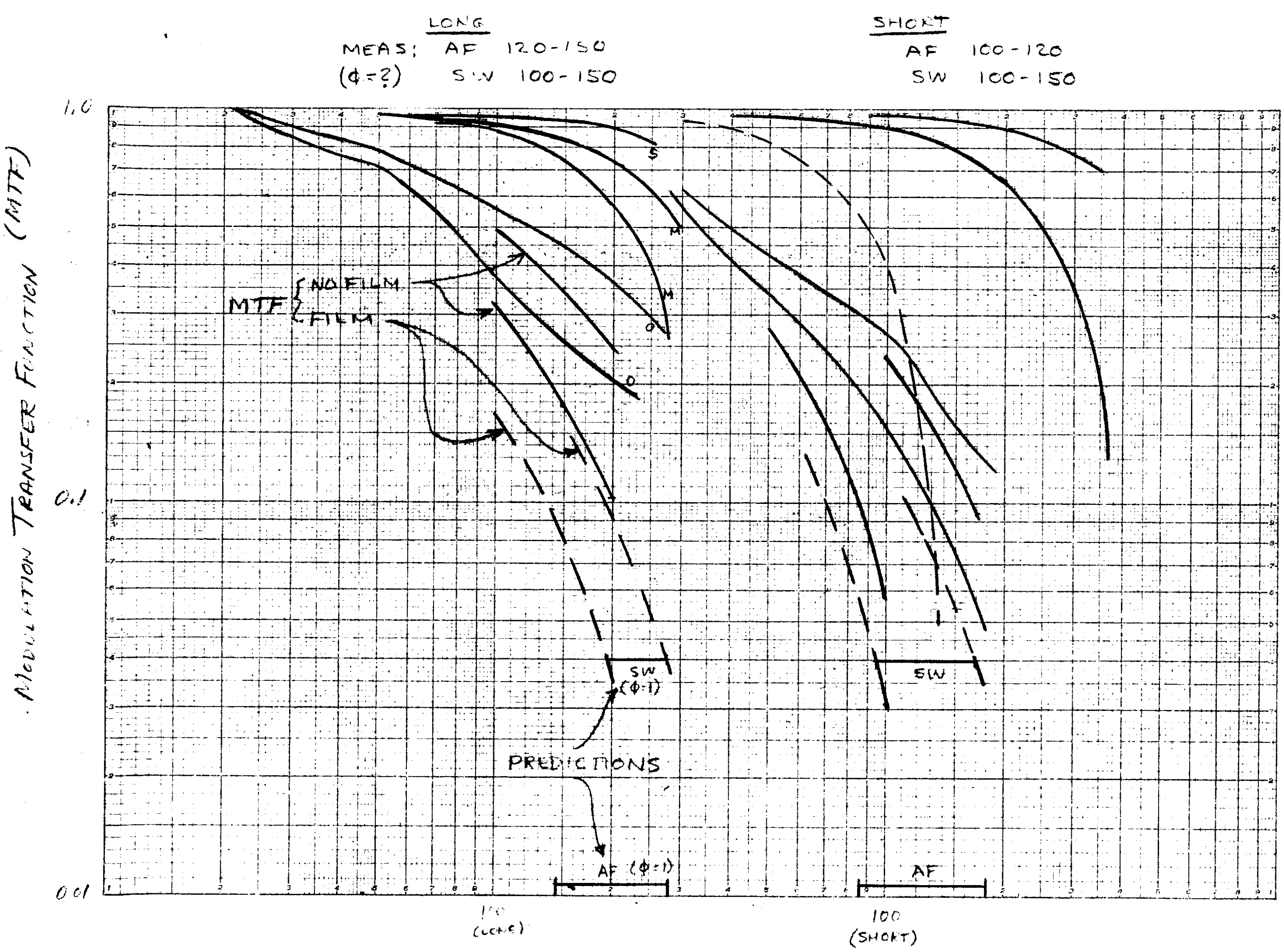
Red curves - Specification for optics. Note that in long direction we have done this well with one scan face of forward unit of System 1A already.

Green curve - Same as for graph 3.

Blue curves - Specification for servo and alignment tolerances.

MDR:mb

GRAPH 1
C-123 LTF-16



GRAPH 2

JEWEL ATT-4

LONG

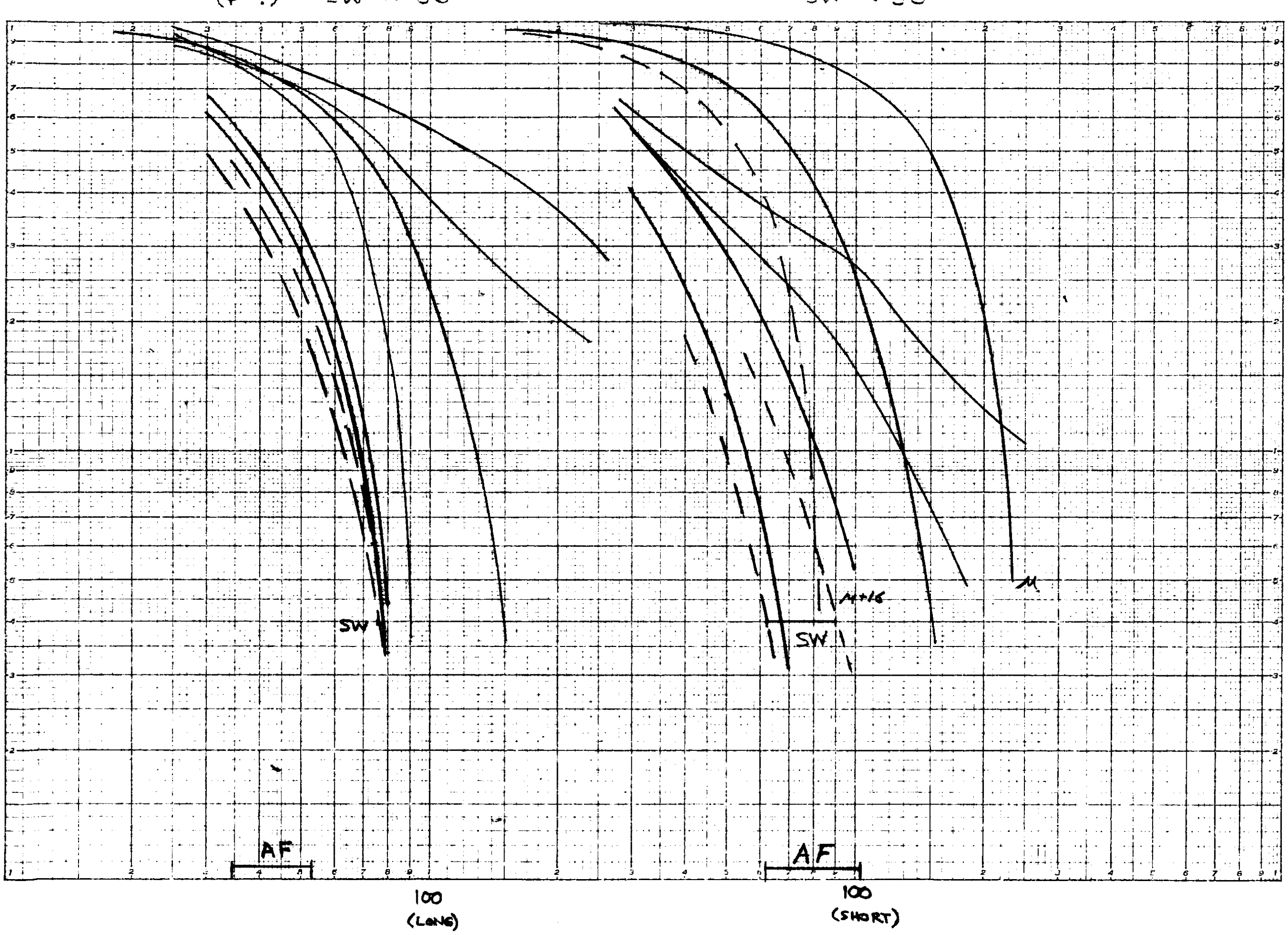
MEAS: AF < 110

(φ=?) SW ~ 55

SHORT

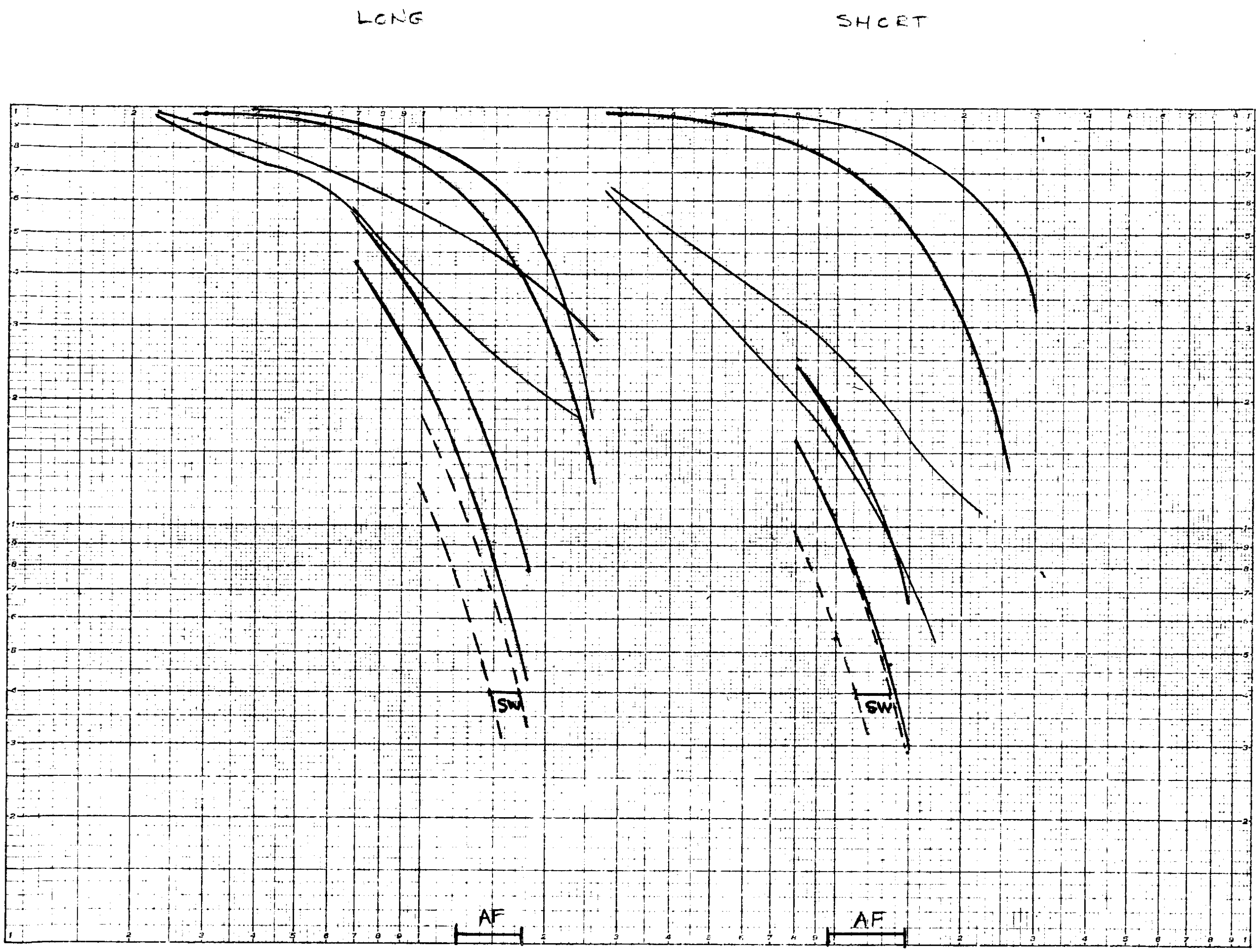
AF < 110

SW ~ 50



GRAPH

1A - JEWEL AT ALT



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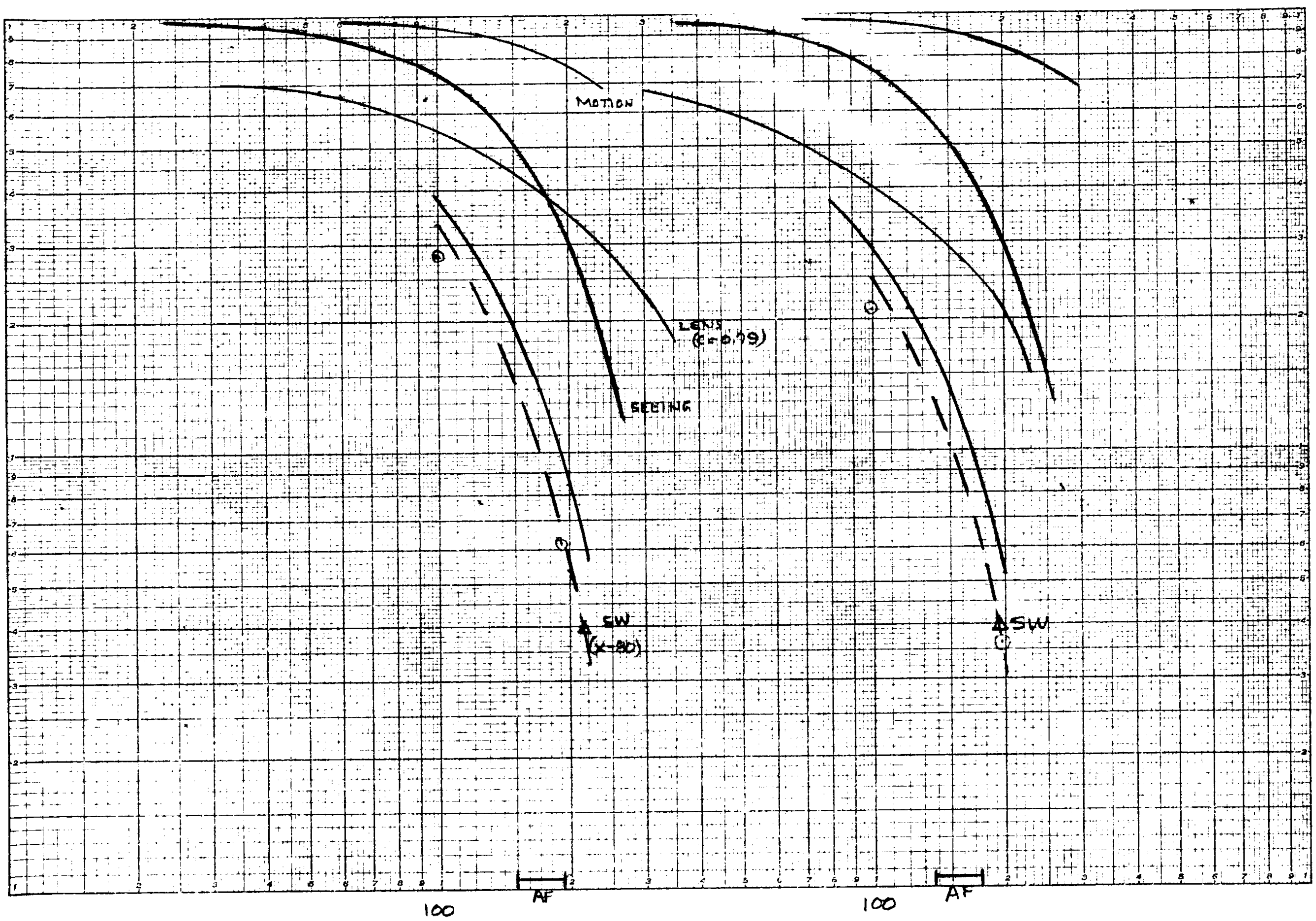
IC IN JEWEL AT ALT.

LONG SHORT



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Attachment 2

~~interested in the amount of information on the ground that can be picked up by the camera, it is the angular resolution which is the fundamental property of the camera rather than the linear resolution (in lines per millimeter) in the film plane. If the angular resolution of the camera is known, and nothing else, the ground resolution can be predicted for any given altitude. If the linear resolution is known, then the focal length must also be known if the ground resolution is to be predicted.~~

~~The fact that diffraction reduces the contrast of the resolved detail indicates that, for low-contrast objects, it would be advantageous to use a system which is capable of resolving finer detail than can be utilized, not because of the extension of the resolution limit, but because the contrast of the resolved detail is enhanced. Figure 1 shows the variation in the image contrast (modulation) with spatial frequency (roughly proportional to the reciprocal of the detail size) of sinusoidal objects for several aperture sizes, showing the improvement in contrast as the aperture is enlarged for any detail size.~~

Atmospheric Seeing

Atmospheric seeing is a physical phenomenon where meterological turbulence disturbs the light path in such a way that light from any point in the object is in effect spread out in the image, thereby reducing the contrast of the finer detail in the image. This spreading is serious enough to limit the angular resolution of any instrument, regardless of its size or quality, which is on the ground and looking up through the atmosphere, to something in the range of 0.5 seconds of arc upward. A seeing limit of 1.5 to 2 seconds of arc is considered to be a good value for rather good seeing conditions.

Most of the work done in this country on seeing indicates that it is associated with a turbulent meterological layer at the tropopause, at an altitude of around 40,000 feet. If the turbulence of this layer

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is the principal cause of image spread due to atmospheric seeing, then the effect as seen from the proposed altitude looking down to the earth should be roughly equivalent to what is obtained on the ground looking up.

Aerodynamic Seeing

Aerodynamic seeing is a similar phenomenon in which the turbulence in the air path is the result of the disturbance of the air by the vehicle passing through it. At supersonic speeds this disturbance consists of a shock wave which separates the disturbed portion of the atmosphere from the undisturbed, a boundary layer next to the surface of the vehicle, and the approximately wedge shaped region between the shock wave and the boundary layer.

At the proposed altitude this structure will have no detectable effect on the image if the flow is strictly laminar. However, if the boundary layer is turbulent, which is a distinct possibility, the image will be degraded in a manner analogous to that of atmospheric seeing.

Leipmann [1] has presented a theoretical analysis of the aerodynamic seeing problem through a turbulent boundary layer as well as an analysis of the deflection resulting in distortion of the image from the same cause. Baskins and Hamilton [2] made wind tunnel measurements which generally corroborate Leipmann's analysis. Stine and Winovich [3] conducted a more detailed study in which Leipmann's analysis is somewhat modified

(1) Liepmann, H. W.: Deflection and Diffusion of a Light Ray Passing Through a Boundary Layer. Rep. SM-14397, Douglas Aircraft Co., May 16, 1952.

(2) Baskins, L. L., and Hamilton, L.E.: The Effect of Boundary Layer Thickness Upon the Optical Transmission Characteristics of a Supersonic Turbulent Boundary Layer. Rep. NAI-54-756, Northrop Aircraft, Nov. 11, 1954.

(3) Light Diffusion Through High-Speed Turbulent Boundary Layers, By Howard A. Stine and Warren Winovich, Ames Aeronautical Laboratory, Moffett Field, Calif., NACA RM A56B21.

(Leipmann had written an equation in which the root-mean-square deviation of a ray is a function of the free-stream density, the free-stream Mach number, and the boundary layer configuration which he presented as a function of the Reynolds number and the coefficient of skin friction. Stine and Winovich found that theory and experiment correlated for density and Mach number, but not for the boundary layer configuration. They replaced Leipmann's boundary layer configuration factor with a factor which did correlate).

Figure 2 was constructed with the aid of Stine and Winovich's formula and data. It shows the limitation of ground resolution as a result of aerodynamic seeing through a turbulent boundary layer as a function of altitude and Mach number, each contour being a contour of constant ground resolution in feet. A constant boundary layer configuration is assumed. (Figure 2 may require adjustment when more data is examined.) If the extrapolation is valid, aerodynamic seeing will limit resolution to approximately one foot on the ground for the proposed altitude and Mach number. The reason for the improvement in resolution above 27,000 feet is that the free-stream density factor drops off faster than the angle subtrended by a unit distance on the ground.

Atmospheric seeing, or aerodynamic seeing, or both, will limit ground resolution to the order of one foot. As the requirement that an image of an object be recognizable is that the imaging system resolves one fifth of the minor dimension of the object, objects smaller than five feet will, in general, not be recognizable.

WINDOW CONSIDERATIONS

~~Special attention has been given to the photographic window because of the physical requirements which are imposed upon it in the proposed system. The window, in forming a physical boundary between the equipment bay and the outside atmosphere, must be able to withstand environmental conditions, must maintain its shape for aerodynamic reasons, and must not contribute to optical~~

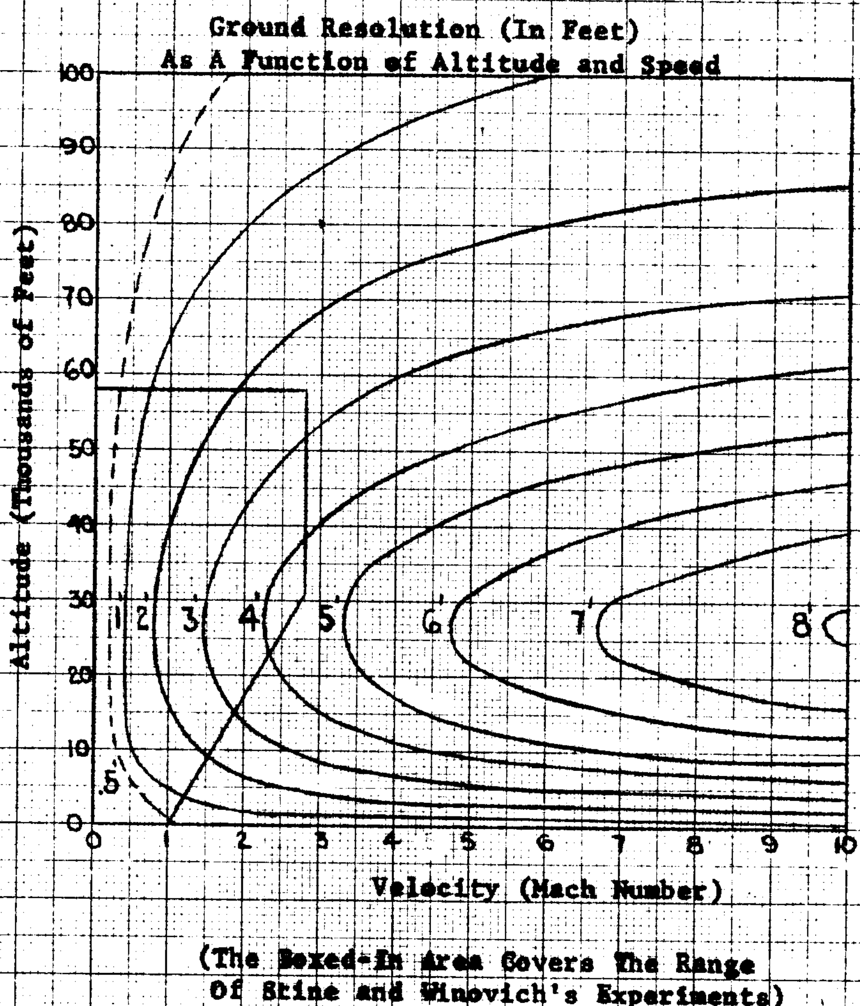


FIGURE 2. LIMIT OF GROUND RESOLUTION DICTATED BY AERODYNAMIC SEEING CONDITIONS OF TURBULENT BOUNDARY LAYER

Seeing

The loss of optical modulation due to aerodynamic effects is considered to be Gaussian with

$$\sigma = 83.3 \times 10^{-6} \frac{\rho_\infty}{\rho_o} \frac{0.2 M^2}{1+0.2 M^2} \quad \text{radians (supersonic)}$$

or

$$\sigma = 111 \times 10^{-6} \frac{\rho_\infty}{\rho_o} \frac{0.2 M^2}{1+0.2 M^2} \quad \text{radians (subsonic)}$$

$\frac{\rho_\infty}{\rho_o}$ = ratio of free-stream to ground density of air

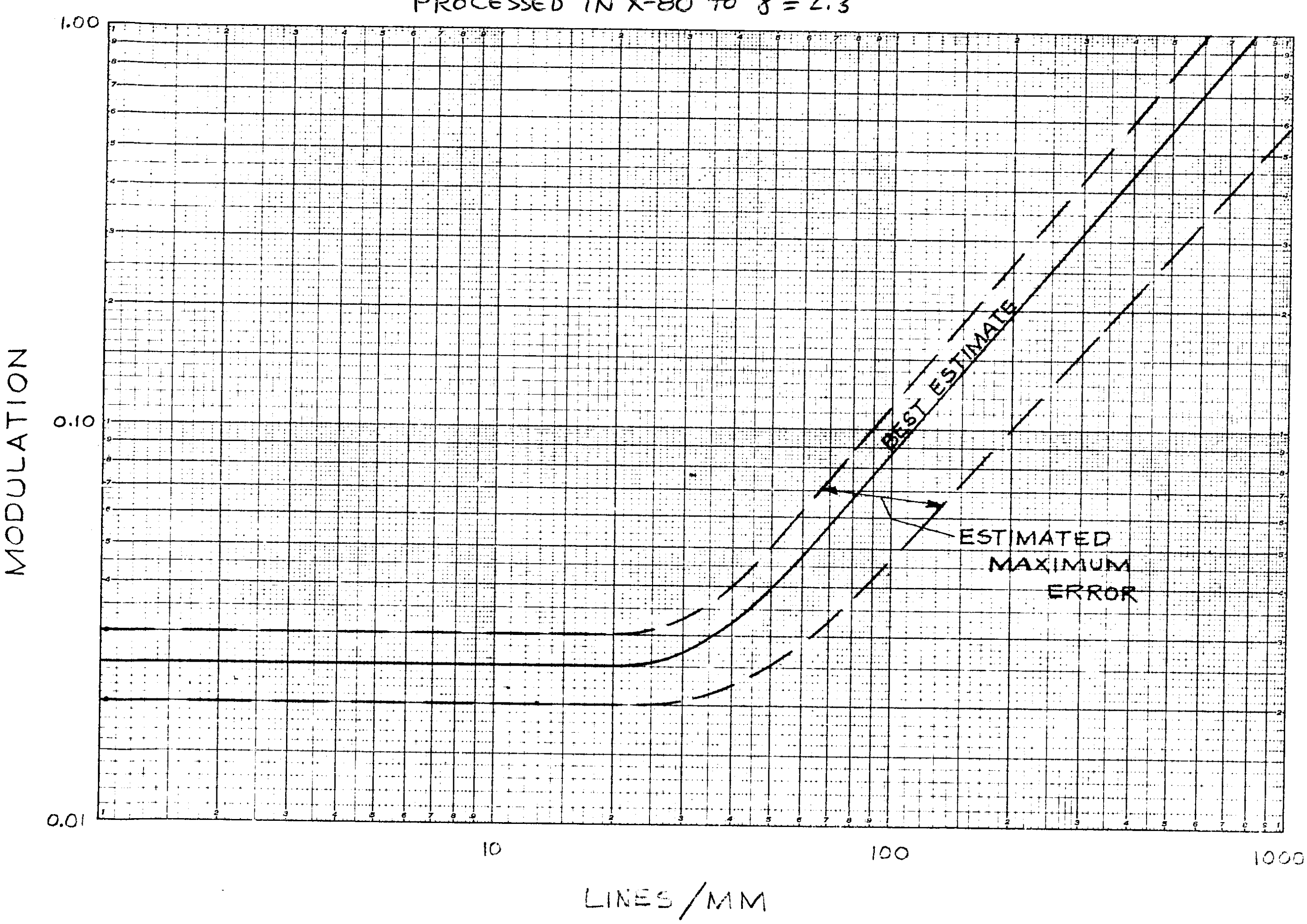
M = Mach No.

Atmospheric seeing is estimated to have $2.4 \times 10^{-6} \lesssim \sigma \lesssim 4.8 \times 10^{-6}$ rad.

These two should be combined to obtain a total modulation transfer function, a Gaussian with

$$\sigma_{TOT} = \left[\sigma^2_{AERO} + \sigma^2_{ATMOS} \right]^{1/2}$$

MODULATION DETECTABILITY CURVES FOR AF TRI-BAR TARGETS & SO-132 PROCESSED IN X-80 TO $\gamma \cong 2.3$



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